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City blood: A visionary infrastructure solution for household energy provision through water distribution networks☆

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ABSTRACT

This paper aims to expand current thinking about the future of energy and water utility provision by presenting a radical idea: it proposes a combined delivery system for household energy and water utilities, which is inspired by an analogy with the human body. It envisions a multi-functional infrastructure for cities of the future, modelled on the human circulatory system.

Red blood cells play a crucial role as energy carriers in biological energy distribution; they are suspended in the blood, and distributed around the body to fuel the living cells. So why not use an analogous system – an urban circulatory system, or "city blood" – to deliver energy and water simultaneously via one dedicated pipeline system? This paper focuses on analysing the scientific, technological and economic feasibilities and hurdles which would need to be overcome in order to achieve this idea.

We present a rationale for the requirement of an improved household utility delivery infrastructure, and discuss the inspirational analogy; the technological components required to realise the vignette are also discussed. We identify the most significant advance requirement for the proposal to succeed: the utilisation of solid or liquid substrate materials, delivered through water pipelines; their benefits and risks are discussed.

1. Introduction

Today, cities rely on multiple utility infrastructure systems of great complexity, which have high associated investment and management costs. There is a wealth of literature which provides evidence of the poor state of Europe's infrastructure [1], highlighting a clear and urgent need for visionary approaches to revolutionising the current system.

In the years ahead, cities and other large communities will encounter resource distribution crises associated with dramatic population flux, with improper water and land resource utilization, with fossil fuel resource depletion, with increased investment overheads, and with spiralling maintenance and management costs; hence sustainable civic systems are necessary in order to minimise the impact of these emergent problems.

Furthermore, recent developments in climate research have also forced governments to select from the best available engineering practices in order to minimise environmental impacts [2,3]. In such circumstances, visionary thinking and radical new ideas can offer promising potential solutions. Had such social, environmental and political factors influenced us sooner, we would most probably have a very different urban infrastructure to that which we have today.

Tremendous effort has gone into the development of environmentally friendly infrastructure, ranging from one-shot local projects to regional and global schemes, such as carbon trading programs. There is, however, one obvious solution to the problems above: eco-friendly, sustainable, multi-functional and flexible infrastructure systems.

In this context, many innovative ideas have been proposed by corporations, scientists, engineers, artists and futurists in order to shape next-generation urban infrastructure systems for improved performance, as measured by increased efficiency, reduced costs, minimal redundant investment and research, and negligible environmental impacts. Examples include "smart grids" and "smart houses" [4], self-sufficient homes and cities [4–6], "smart cities" [7], new approaches to integrated infrastructure development [8], and even the provision of all utility services via one single infrastructure [9].

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This study highlights a key question in utility infrastructure foresight: “How different might our infrastructures look if, when we began to construct them, we’d known all that we know now?” Furthermore, it advances the radical concept of a combined household energy and water delivery infrastructure which might be made possible by emerging technological developments and advances.

The dominant technological challenge identified by this study is the distribution of a novel energy carrier or fuel via extant water distribution systems. Potential fuels and energy carriers include solid and liquid substrate hydrogen carriers, fossil fuels and biofuels. The ultimate aim of the study is not to advocate for the adoption of any particular solution, but to provoke discussion and thinking toward shaping a future infrastructure system which is environmentally friendly, sustainable, multi-functional, manageable and flexible; as such, we encourage the scientific community to consider this radical approach.

Section 2 presents the methodology used in the paper, while Section 3 discusses the results and findings; Section 4 presents the conclusions drawn from our evaluations and analyses.

2. Methodology

This study adapts an objective-focused technique [10] in order to evaluate a possible future infrastructure solution based on the All-in-One concept [9]. The methodology includes a series of five processes represented in a triangle, as shown in Fig. 1; it begins with the proposed vision, and each process then takes up the output of the one preceding it. The triangulation represents the filtering performed in each process.

The first step, key process identification, aims to define the engineering processes required to achieve the given vision. Next, the functional requirements of the selected key processes are analysed in the second step. The third step involves a search process to identify technologies which satisfy the requirements defined for the selected key processes; the selected technologies are then evaluated in the fourth process. The final step is the preliminary economic feasibility assessment of the suggested solutions.

The details of the original vision and the methodological processes are discussed in the following subsections.

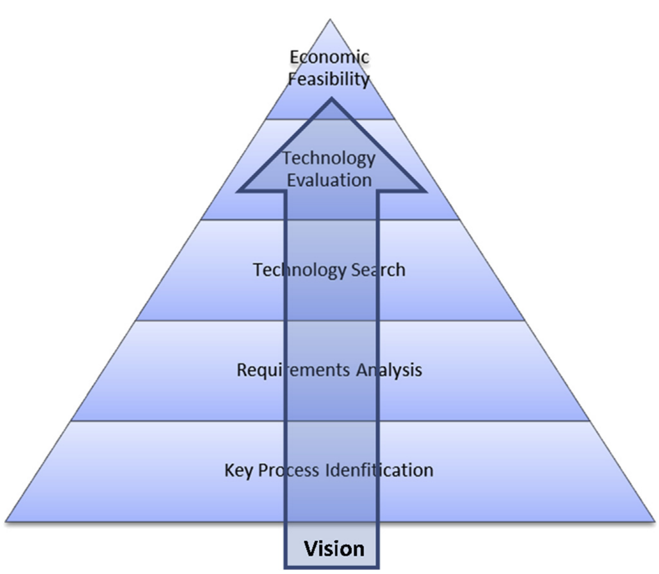

Fig. 1. Technological feasibility assessment and gap identification framework.

2.1. Vision

We propose the joint provision of energy and water through a single pipeline network. This approach has the potential to eradicate the redundant investments attendant on multiple discrete infrastructures, and to reduce negative environmental impacts. This system resembles a city circulatory system, and was originally proposed as a potential “All-in-One” infrastructure solution [10].

The cell is the basic structural unit of the biological body; its needs are supplied by the capillaries and blood vessels. A house is the basic functional unit of the urban body; its needs are supplied by networks of infrastructure. Blood is the carrier liquid which delivers and collects water, energy, and waste products throughout the body via the arteries and veins of the circulatory system.

Of course, an analogy can only stretch so far, and comes complete with its own pros and cons – so while a biomimetic approach might provide a workable solution to urban infrastructure improvement, such a solution must be assumed to come with inherent challenges alongside its advantages, and we endeavour to explore both in the sections to follow.

2.2. Key process identification

The main aim of this visionary study is to encourage people to question the assumed need for multiple discrete infrastructure systems, and to dare to think radically about the future of utility service provision. Four key processes required for a viable system have been defined, as follows: energy generation and water supply (process 1); unified energy and water delivery (process 2); household energy and water utilisation (process 3); and wastewater management, onsite treatment and waste to energy technologies (process 4).

Process 1, the “generation” phase, involves combining energy carriers with water prior to distribution: in the “blood of the city” analogy, this represents the lungs, where oxygen is combined with haemoglobin in the blood; in the proposed distribution system, this is the power generation unit where the energy is stored in the energy carriers and fed into the city blood.

Process 2 is the distribution of the energy carriers within the water, process 3 is the separation of the energy carrier from the water at the final consumption point. This paper focuses only on the innovative part of the proposed system, namely the unification of energy and water delivery (process 2); readers are directed to the extant literature for evaluations of suitable alternatives for future energy and water provision, household utilisation, and waste management technologies and components (processes 1, 3 and 4).

A graphical illustration of the “blood of the city” vignette and its key processes is presented in Fig. 2.

2.3. Requirements analysis

The technological feasibility of an infrastructure project depends on its capacity to fulfil certain physical requirements, such as the volume of water which must be delivered per household by a pipeline system. Here we discuss the requirements we assume of our proposed system.

Firstly, required levels of household energy, water, and waste disposal provision were calculated with reference to statistical data for current consumption levels in the UK; then some baseline assumptions were made in order to extrapolate a projection of future household utility requirements. Secondly, the infrastructure’s throughput requirements – such as the volume of water to be distributed, and the energy-carrier mass percentages in the joint delivery system – were calculated.